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Testing, Evaluation, and Design Support of the Minus Eighty-Degree Laboratory Freezer (MELFI) Payload Rack

Punan Tang, Ph.D
13842 Placid Brook CT. Houston, TX. 77059
Ptang1@prodigy.net

Jerry Goodman, and Christopher S. Allen
Mail Code SF22
NASA JSC
2101 NASA Rd 1
Houston, TX, 77058
jerry.r.goodman@nasa.gov
christopher.s.allen@nasa.gov

1. INTRODUCTION

The Minus Eighty-degree Laboratory Freezer (MELFI) for International Space Station (ISS) payload rack is a French provided facility developed to serve as a cooling and low temperature storage device for preserving experiment specimens, samples, and supplies. (*Figure 1*. This facility will be provided to the International Space Station ISS as laboratory support equipment and will initially be installed in the US Laboratory module, but will later be moved to the Japanese Experiment module(JEM). The MELFI Payload was required to meet the acoustic requirements given in ISS specification SSP 57000 document [1].

In early design and development stages, MELFI designers had addressed the issues of the MELFI payload rack's acoustics compliance with SSP 57000 requirements, and conducted some preliminary analysis. Component level acoustical tests based on a prototype MELFI model were also performed. [2,3]. The MELFI rack's acoustical performance was predicted based on the Brayton machine's individual component noise level characteristics. However, the rack's actual acoustical characteristics were not known until September 2001 when the MELFI rack was tested acoustically in an independent acoustical test lab at ONERA in France [4]. The test results revealed that the MELFI was not able to meet the NC-40 continuous noise requirement of SSP 57000 due to excessive high frequency noise above 500Hz. The non-compliance was demonstrated over a wide range of MELFI operational modes, which were defined by the Brayton machine's rotating speed, ranging from 72000 revolutions per minute (rpm) to 92000 rpm.

In November 2001, NASA JSC acoustic specialists and MELFI design engineers conducted a joint acoustical test and noise source investigation at Astrium in France. The MELFI's exceedance of the SSP 57000 requirements was re-verified and levels were shown to be consistent with the previous ONERA tests.

During the test at Astrium, the original acoustic treatments were evaluated and analyzed on the flight rack. Some additional noise reducing design concepts and approaches were also developed and these test results were very promising. This test data validated the proposed new noise control designs for the flight hardware. Design implementation and verification test plans were also discussed. Since then, the MELFI flight rack has undergone additional various testing and hardware changes wherein acoustic designs were improved. Further, these improvements in the MELFI acoustic design were evaluated during several additional test campaigns conducted in March 2002 at Astruim, and in April, and June, 2002 at NASA Kennedy Space Center (KSC). Final acoustics verification tests were conducted at KSC in September 2002.

This paper describes the details of the MELFI acoustic design approaches, analysis and testing, and also presents the acoustic status of the final MELFI flight rack (FM1). In addition, several of the noise reduction designs that were evaluated are discussed, along with their corresponding acoustic benefits. It is thought that this paper will be beneficial to other payload rack developers and others trying to reduce the noise of similar-type hardware. The results show that the MELFI with the developed changes was able to meet or be brought down close to SSP 57000 requirements using developed noise control solutions.

2. MELFI ACOUSTICAL DESIGN DESCRIPTIONS AND PERFORMANCE EVALUATION

Based on previous analysis and test results during primary design periods, the main noise source of the MELFI Rack was identified to be the cold box, which is installed by a very rigid mounting in the upper right-hand portion of the rack. The noise is radiated directly by the cold box's metal case into the surrounding internal spaces and transmitted along paths to the external space through the rack walls and various openings and through acoustic leakage. The noise generation mechanism of the cold box's high frequency noise was caused by vibration of the cold box's internal components and metal case; which was driven by the Brayton machine's high-speed turbo pumps [2]. The narrow band frequency analysis of the cold box noise was found to be dominated by a 1 kHz, high-amplitude tone and its harmonics up to 8 kHz. In examining the MELFI rack's acoustic radiation pattern, the loudest area in front of the rack was found to be directly in front of the cold box. The Brayton machine's rotational speed is the factor that determines the noise levels and frequency content. At 87000 rpm, which is the highest of the Brayton machine's normal working speed, the highest noise levels are generated.

In consideration of the Brayton machine's normal operational speed range, and the MELFI rack's internal space and restrictions, as well as the cold box's noise emission paths, several acoustic designs were recommended to the MELFI designers after the November 2001 tests at ASTRIUM. These designs or modifications included the redesign of acoustic cold box wraps using an acoustic barrier panel material (See *Figure 2, white cover around cold box)*, acoustic foam lining on the rack internal walls, including the both sides, top, and back, acoustic foam filling in the existing gaps, spaces and cavities. Also implemented were acoustic wrapping of the cold box's suction and discharge pipe and tubes, as well as increased foam for improving the acoustic absorption, and blocking noise transmission through the cold box cabinet front door with barrier material and lining methods. The performance of these recommended designs were evaluated in the March 2002 test campaign, performed at the ASTRIUM facility. These test results showed very promising benefits and significantly reduced MELFI Rack noise levels. At this time an additional acoustic barrier/foam panel covering the exterior front surface of the cold box closeout panel was implemented. Its use helped to bring the MELFI noise down close to the NC-40 requirement [5]. (*Figure 3)*. The basic acoustical materials employed in MELFI acoustical designs are the ISS flight certificated acoustical material: Bisco wrap, nomex fabric, nomex felt, and Melamine foam. The cold box wrapping uses heavy double layers of the Bisco wrap with felt filling.

The above design changes were developed, tested for effectiveness, and recommended for MELFI's flight hardware implementation. Flight verification tests were scheduled on the MELFI FM1 flight hardware rack at KSC in Florida. *Table 1* summarizes the MELFI engineering evaluation and verification test milestones.

During the April 2002 acoustic tests at KSC, the FM1 MELFI fight hardware with the acoustical design implemented by ASTRIUM was tested. However, only engineering evaluation and performance comparisons were obtained due to the lack of an appropriate acoustic test environment. During this test, the FM1 was configured with cold box #1 and Brayton Machine #1 and was located in a large reverberant room. A temporary chamber was built to isolate the noisy environment from the test set-up and was installed around the MELFI rack. However, it was discovered that the data was corrupted by reverberation.

The series of resulting engineering evaluation tests did show acoustic improvements to modifications, but only relative levels and approximate reductions were obtained [6].

In June 2002, further MELFI acoustic testing was conducted at KSC in the same temporary chamber, but a 2-inch-thick acoustic lining was installed to line the interior walls of the chamber to absorb the acoustic reflections. In this fashion an approximate anechoic environment in the frequency range of interest, 1 kHz octave band and above, was established. Measurements at 500 Hz were also acquired but were somewhat contaminated by background noise and reverberation. The chamber dimensions also limited the amount of space to the sides and top of the rack so that only measurements in the front of the rack could be obtained. The MELFI FM1 for this test had a slightly different configuration. For this test a second Brayton Machine, BM2, was used instead of BM1. However, the test results were promising and showed levels that were very close to the NC-40 requirement [7].

3. FINAL FLIGHT HARDWARE VERIFICATION/ACCEPTANCE TEST

After the June 2002 testing, the MELFI FM1 Rack had undergone further significant hardware changes. Specifically, the original cold box was removed and was replaced with a new cold box, CB2. In addition, the original Brayton Machine (BM1) was reinstalled. Therefore, the final flight hardware combination for the FM1 rack was different from the combination used in prior tests and evaluations. In addition, the acoustic treatments in the reconfigured FM1 flight rack were also slightly different from the configurations of the previous tests. This difference was that as part of the cold box change-out, the acoustic foam blocks of triangular cross-section that had previously been installed in the two lower corner cavities that exist between the cylindrical cold box and the cavity surrounding the cold box were removed. These acoustic foam blocks were thought to be a significant part of the original acoustic remediation recommendations, and were positioned to reduce the noise that propagated down to the lower portions of the rack. These acoustic foam blocks were installed in the rack during testing at ASTRIUM in 2002 and at KSC in June and April 2002. These blocks were removed during the September 2002 tests. Additionally, the MELFI designers made modifications to the exterior acoustic panel in order to obtain a tighter fitting attachment to the front of the cold box.

The final verification tests were conducted in the same temporary acoustic chamber as in the June tests [7]. (*Figures 6-8)* show a summary of the test results from all of the test campaigns, including the final verification testing performed at KSC. The MELFI FM1 final flight hardware showed its acoustic emissions to be reduced by as much as 14 dB at 8 KHz band compared with the early ONERA test results.

4. MELFI ACOUSTIC TEST SETUP

All of the MELFI acoustic tests, occurring from November 2001 to September 2002 were conducted to determine compliance with SSP 57000. For the MELFI's continuous operational mode, SSP 57000 requires the octave band sound pressure levels in the frequency range from 63 Hz to 8 kHz at the maximum noise location at a distance of 2 feet from any point on the MELFI rack to be at or lower than the NC-40 curve.

During the February and March 2002 tests at ASTRIUM, 15 microphone locations were used to obtain an approximate MELFI global noise distribution, and to identify the maximum noise location. For the purpose of the comparison, these 15 microphone locations were exactly the same as those used for the ONERA test. Since the March test data had revealed that the highest noise levels were at the six microphones in the front of the MELFI Rack, the subsequent testing only used these six locations. These six measurement locations were consistent with the previous tests and were located 2 feet from the front face of the MELFI rack and were consistent with verification requirements stated in SSP 57000. (*Figure 5)*.

During all tests shown in figures 6-8, the MELFI noise levels were acquired over a frequency range from the 1 kHz through the 8 kHz octave bands. The background noise over this frequency range was at least 6 dB below the MELFI noise. This frequency range was also the critical range needed to verify compliance to the NC-40 requirement since MELFI was known to exceed requirements at these high frequencies.

During the early MELFI acoustic evaluation at ONERA, measurements in a large hemi-anechoic chamber showed that the MELFI was compliant at octave band frequencies below 1 kHz. In fact, it was found that all acoustic emissions at frequencies less than 1 kHz were far below NC-40. The ONERA data are given in *Reference 3*.

During all testing, the Brayton machine was running at nominal speeds of 75000, 85000 and 87000 rpm. It was found that Brayton machine's rotational speed could only be set within ±170 rpm, and so repeatability tests of the MELFI Rack's noise emission variations were conducted in the April, June and September 2002 tests to understand the variability of the data.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

(1). ONERA test results in August 2001 and Astrium test results in November showed that the MELFI noise was exceedingly high, and that MELFI was non-compliant in regards to NC-40 (SSP 57000 requirement) in the octave frequency bands from 1 kHz to 8 kHz. The original acoustic design did not show significant benefits in suppression of the MELFI noise for compliance. During the March 2002 tests at ASTRIUM, noise reduction concepts were demonstrated and reduced the MELFI noise to levels that were close to the NC-40 requirements.

(2). Although some variation existed, all testing performed in April, June, and September 2002 at KSC verified the promising results of the new designs. These tests showed some variation in the test results. However, it is suspected that the main reason for these was that the flight hardware components were different for each test.

(3). The tests in September 2002 were final tests on Flight hardware rack (FM1); its non-compliance was shown to occur only at 85000 and 87000 rpm. The maximum exceedance compared with NC-40 was 4 dB in the 2 KHz octave band. Compared with the original MELFI noise level (See ONERA data [3]), the maximum improvement was as much as 14 dB at 8 KHz band.

(4). The flight configuration external acoustic panel was shown to effectively reduce the MELFI noise emissions. This was verified in both the April and June 2002 tests. In addition, it was also verified that MELFI rack noise could be reduced to a level compliant with the NC-40 requirement if an enhanced or extended external acoustic cover is applied to the MELFI rack front surface. (Figure 4). These conclusions were derived from the test results of the April and June 2002 tests. It was determined; however, that the FM1 design was adequate as is, and whether these changes are made in the next generation MELFI is to be determined.

6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of this work by Dr. Christine Taddei, and the MELFI Project Group of ASTRIUM Space Company in Toulouse, France.

7. REFERENCE

[1]International Space Station SSP57000 - Pressurized Payload Interface Requirements Document.
[2]M Chegancas, M. Prescher, "Vibroacoustic Survey of the DM Bratton Sub-System", October 1996
[3]C. Taddei, P. Humbert, "Audible Noise/Vibration Analysis Report for the Brayton Sub-System", March 1998
[4]D. Biron, S. Pauzin, "MELFI Rack Acoustical Test report-ONERA Tests", September 2001
[5]P.Tang, J. Goodman, "ASTRIUM MELFI Acoustical Test Report- No# 030302"
[6]P.Tang, J. Goodman, "KSC MELFI Acoustical Test Report- No#1- 042702"
[7]P.Tang, C. Allen, J. Goodman, "KSC MELFI Acoustical Test Report- No#2-062002"
[8]P.Tang, C. Allen, J. Goodman, "KSC MELFI Acoustical Test Report- No#3-092702"

Item	Test Date and Location		Hardware Combination In MELFI Rack FM1	Acoustical Design Development and remarks
	Date	Location		
1	09/03, 2001	ONERA, France	CB1&BM1	Original rack without acoustical redesign. It was used as MELFI's original noise radiation baseline.
2	11/19-11/20, 2001	ASTRIUM, Toulouse, France	CB1&BM1	Tests were conducted by NASA JSC on MELFI rack with original ASTRIUM acoustical designs
3	02/31—3/01, 2002	ASTRIUM, Toulouse, France	CB1&BM1	NASA JSC acoustic design recommendations and design concept evaluation
4	04/26-28, 2002	KSC, Florida, USA	CB1&BM1	Acoustic flight verification tests. Additional design concepts and evaluation such as rack front external panel effects.
5	06/16-18/, 2002	KSC, Florida, US	CB1&BM2	The same as 4, above, except using an appropriate acoustic test environment, and also more tests on external acoustic panel effects.
6	09/26-27, 2002	KSC, Florida, US	CB2&BM1	Final Flight rack acoustic verification tests with the same acoustical designs, but without two-triangle acoustical foam block underneath cold box corners. Other approaches were tested such as dual external acoustic panels on the front of the MELFI.

Table 1. Summary Table of the MELFI Acoustic Tests and Design Development

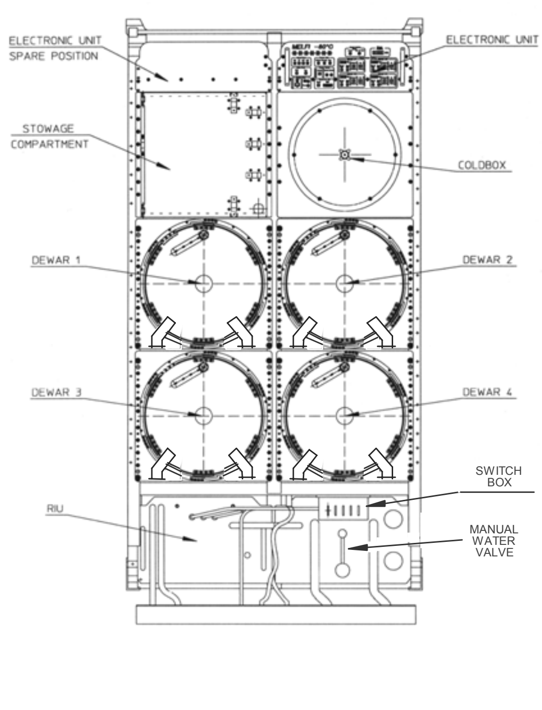


Figure 1. MELFI Rack Description

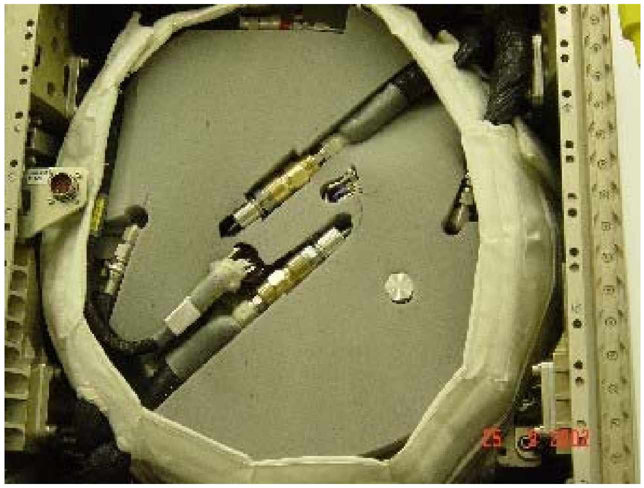


Figure 2. Cold Box Acoustical Treatment- Acoustical Enclosure

Figure 3. MELFI Rack Acoustical Treatment- Acoustical Barrier Panel

Figure 4. MELFI Acoustical Barrier- Rack front Acoustical Cover

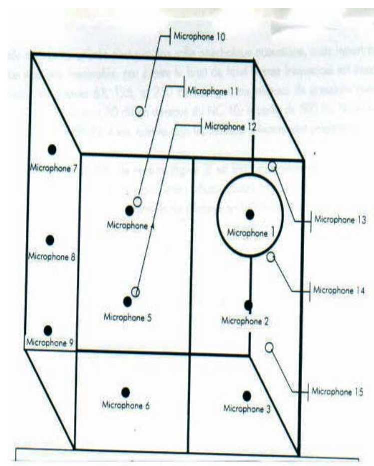
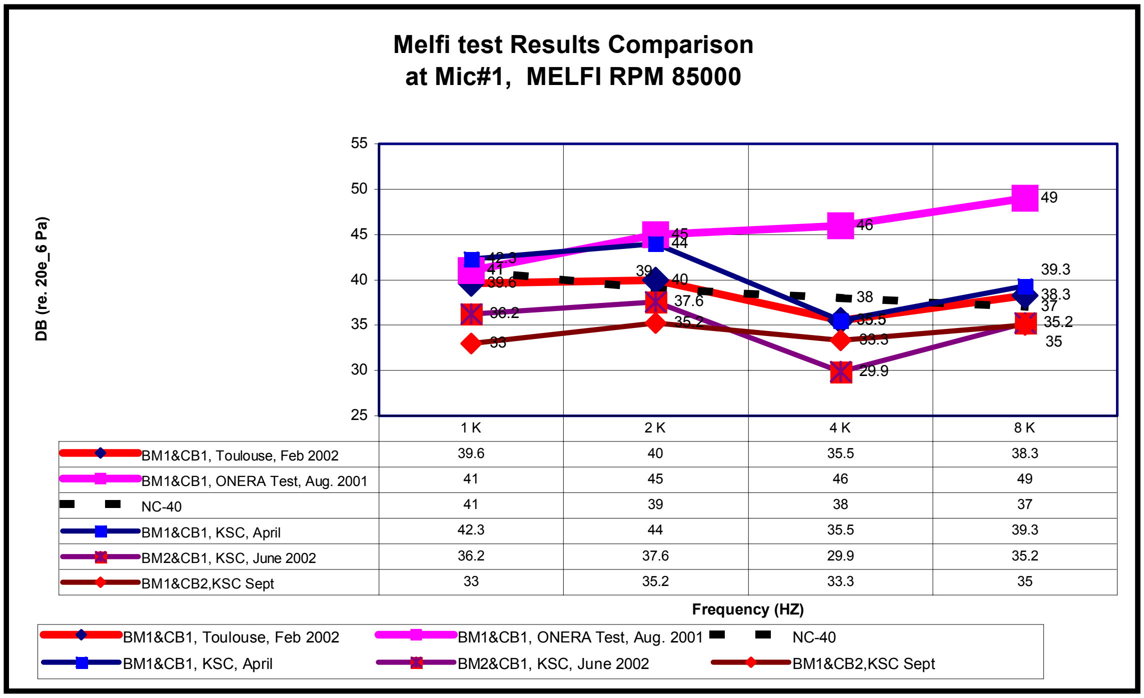
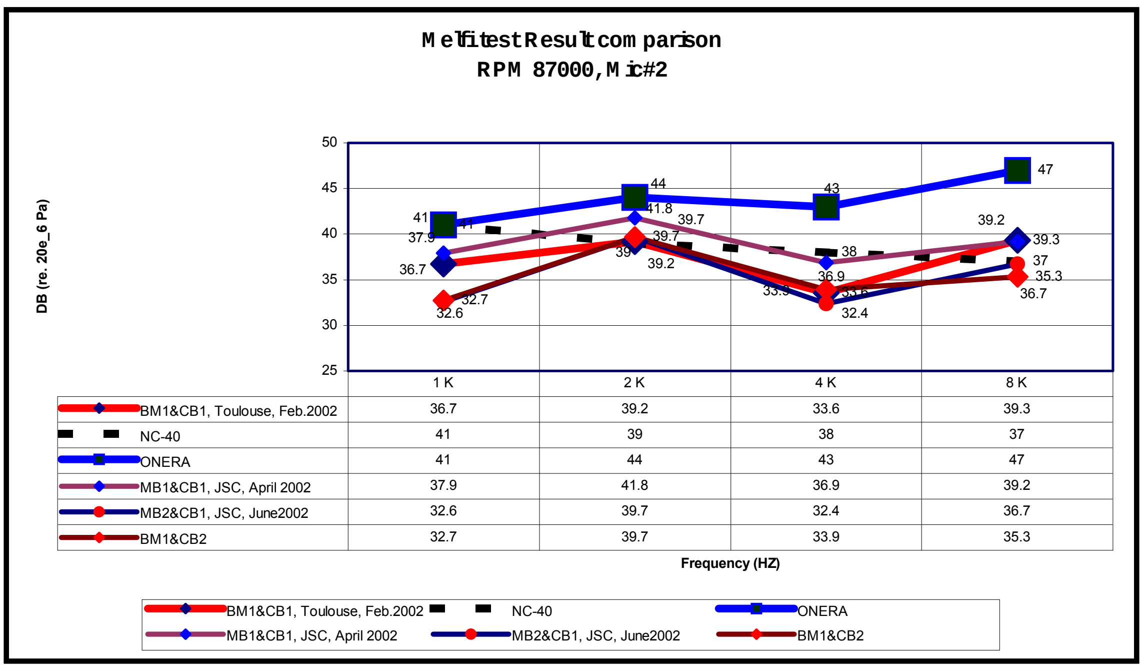


Figure 5. MELFI Acoustical test Layout. Each surface is 2 feet from corresponding MELFI rack surface. There is no top or bottom surface.



	1 K	2 K	4 K	8 K
BM1&CB1, Toulouse, Feb 2002	39.6	40	35.5	38.3
BM1&CB1, ONERA Test, Aug. 2001	41	45	46	49
NC-40	41	39	38	37
BM1&CB1, KSC, April	42.3	44	35.5	39.3
BM2&CB1, KSC, June 2002	36.2	37.6	29.9	35.2
BM1&CB2,KSC Sept	33	35.2	33.3	35

Figure 6. MELFI Acoustics with/without Acoustical treatments at 85000 RPM



	1 K	2 K	4 K	8 K
BM1&CB1, Toulouse, Feb.2002	36.7	39.2	33.6	39.3
NC-40	41	39	38	37
ONERA	41	44	43	47
MB1&CB1, JSC, April 2002	37.9	41.8	36.9	39.2
MB2&CB1, JSC, June2002	32.6	39.7	32.4	36.7
BM1&CB2	32.7	39.7	33.9	35.3

Figure 7. MELFI Acoustics with/without Acoustical treatments at 87000 RPM

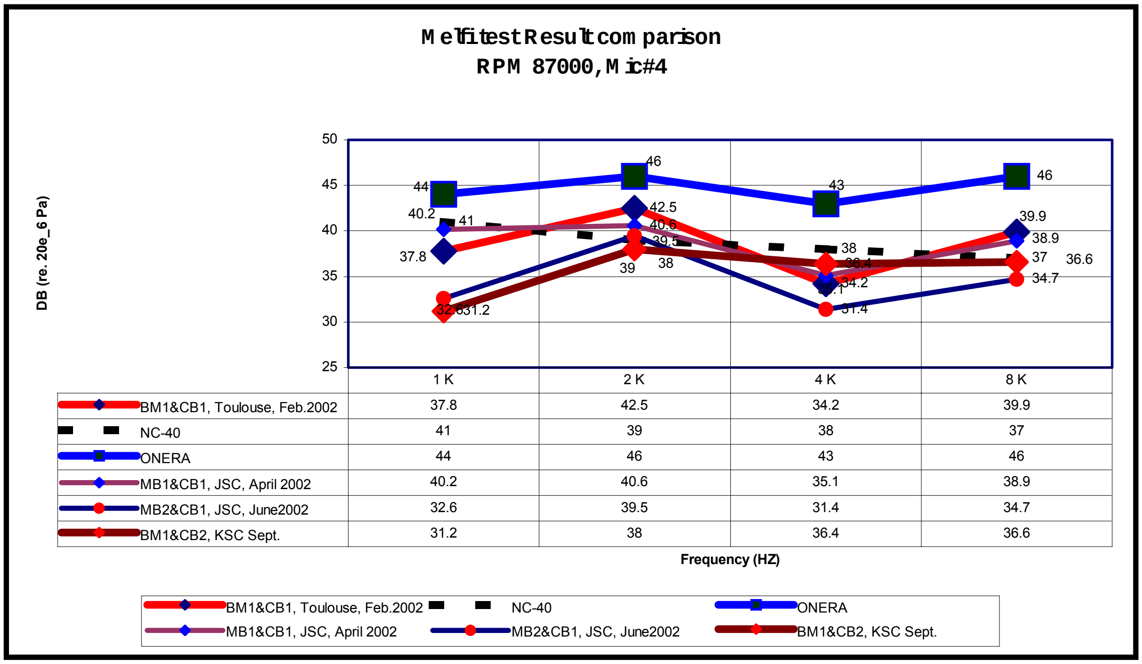


Figure 8. MELFI Acoustics with/without Acoustical treatments at 87000 RPM